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**Fakulta baníctva, ekológie, riadenia a
geotechnológií**



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SELECTED RESULTS OF RESEARCH AND DEVELOPMENT PROCESS OF METAL FOAM STRUCTURE FOR ENERGY USE

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Summary: *The paper deals with research and development process of metal foam structures for energy purposes conducted in the Department of Renewable Energy Sources, Faculty BERG, namely with one stage consisting of a fluid processes analysis characterizing the various operating conditions of solar vacuum tube collector with metal foam element through CFD simulations. Evaluated manifold header for vacuum tube solar collector was assessed in 2D computational domain of Ansys Fluent software. The main objective was to characterize the fluid flow in the structure of the metal foam, on basis of which would be possible to modify the shape of the heat exchange chamber to form taking into account trajectories of flow, so that the medium flows at a constant velocity in the entire volume of chamber. Final evaluation represents velocity maps of evaluated manifold header, which is for better clarity compared with common used manifold header for solar vacuum tube collector.*

Key words: *manifold header; metal foam; CFD analysis; heat pipe;*

1 INTRODUCTION

Research of metal foams and their potential application in the energy utilization takes place at the Department of Renewable Energy Sources, Faculty BERG since 2008. This activity is characterized by a number of development paths involving research of the metal foam structure at the macro level, the implementation of structural elements based on metal foams in devices using renewable energy (especially solar energy), designing the heat exchangers and, finally linking metal foams and heat accumulators. These activities are designed also in collaboration with students at all levels of study - bachelor, master and doctoral studies. The output is therefore not only the publications in the highest category, utility models, designs, but as well as awards for students involved in the solution of partial research objectives.

The article presents the particular stage of research based on an analysis of structural adjustment of commonly used solar vacuum tube collectors by using metal foams in the area of the manifold header. Modification of the evaluated manifold header consist in adding of construct elements made of metal foam, which increase the heat exchange surface between the heat pipe condenser casing and the flowing heat transfer medium. Specific and complete description of the manifold parts and its test operation is discussed in (Rybár and Beer, 2015), (Rybár et al., 2013), (Rybár and Beer, 2013) and therefore will not be described further.

2 METHODOLOGY

Presented analysis of solar collector manifold header covers fluid characteristics of the heat transfer medium, which were determined using 2D CFD analysis and include, in particular, the fluid velocity in the described heat exchange chambers and channel itself. For better clarity were evaluated features of innovated manifold header compared with commonly available manifold header for solar vacuum tube collector. The role of the CFD analysis was to characterize the fluid flow in the structure of the metal foam, on the basis of which would be possible to modify the shape of the heat exchange chamber to form responding to trajectories of flow in a way that the medium will flow at a constant velocity in the entire heat exchange chamber. The second task was to identify potential risky spot in terms of turbulent regions, respectively areas with sudden changes in pressure of heat transfer medium. For the purposes of simulation were created models of manifold headers, which could be due to the axial symmetry simplify to the 2D shapes.

This simplification had a positive impact on the computing time and demands on used hardware, free capacity thus could be used for enhancement of the computational mesh quality. The model consists of a body representing the area of medium flow, condenser casing and in case of modified manifold headers also heat exchange chamber made of metal foams, as it can be seen in Fig. 1, where 1,4 - condenser casings, 2,3 - heat transfer medium flow canals, 5 - heat exchange chamber.

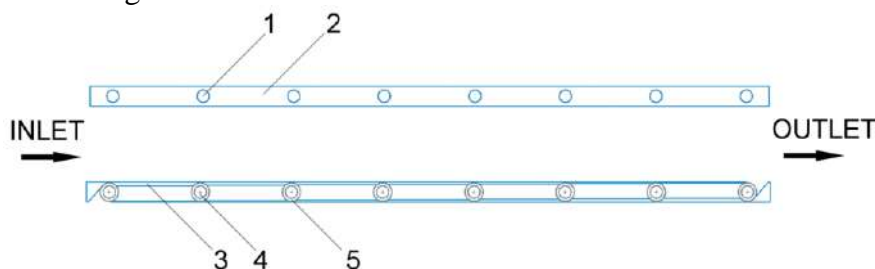


Fig. 1 Schematic view of 2D model of modified manifold header (down) and conventional manifold header (up)

On 2D models were applied discretized non-structured mesh grid (Fig. 2), which in the case of modified manifold header containing 36 257 cells and had a value of skewness of 0.59 which is according to (Ansys, 2006) sufficient value. Computational mesh of conventional manifold header containing 29 574 cells and value of skewness was 0.48, which characterized acceptable data representation.

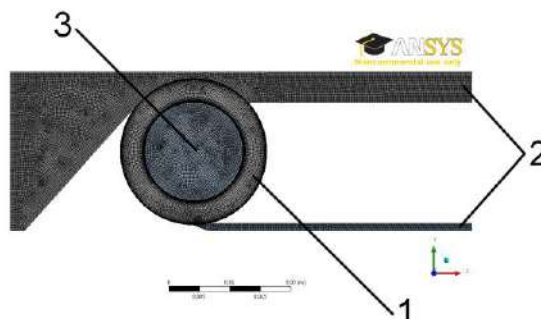


Fig. 2 Sample view of computational mesh for modified manifold header (1 - heat exchange chamber, 2 - flow channels, 3 - condenser with casing)

The resulting CFD analysis was carried out in software Ansys Fluent, in which was created the computational grid and added boundary and initial conditions of the simulation.

The used flow velocities with which the individual simulation worked were calculated in relation to the size of the modified and the conventional manifold header and desired flow rate 30, 60, and 120 kg.h⁻¹ what corresponded to velocities of 0.016; 0.032; 0.064 and 0.128 m.s⁻¹. Mathematical model worked with SIMPLE algorithm and discretization of second order. Pressure equation was solved with PRESTO scheme. Boundary conditions of flow analysis consisted of chosen area of flow that was defined by the inlet and outlet boundary and outer boundaries, i.e. fixed boundaries, through which there is no flow. The area of calculation was defined with a non-compressible flow.

Inlet boundary was defined with density, pressure, flow velocity and outlet boundary with static pressure. Simulation has stationary character and was carried out in 5000 iterations.

3 RESULTS AND DISCUSSION

Basic input parameters of CFD analysis defining metal foam in terms of the flow of media are permeability K and the coefficient of hydraulic resistance C_1 , which are based on Ergun equation and defined in Eq. 1 and Eq. 2 (Ergun, 1952).

$$K = \frac{D_p^2}{150} \cdot \frac{\phi^3}{(1-\phi)^2} \quad (1)$$

$$C_1 = \frac{3,5}{D_p} \cdot \frac{(1-\phi)}{\phi^3} \quad (2)$$

where, D_p is mean pore diameter [mm] and ϕ is porosity of metal foam [-]. These parameters form the basis for the definition of the metal foam in the analytical software Ansys Fluent, which was used within the solution presented in the paper. Summary of calculated parameters is shown in Tab. 1. Equally essential parameter of simulation is to determine the nature of the flow in the studied element by determining the Reynolds number for mean pore diameter Re_P [-] according to Eq. 3

$$Re_p = \frac{\rho \cdot U \cdot D_p}{\mu} \quad (3)$$

where ρ is fluid density [kg.m⁻³], U is Darcy velocity [m.s⁻¹], D_p is mean pore diameter of metal foam [m] and μ is dynamic viscosity [Pa.s]. Because of the low values of Reynolds number Re_p (0.005 to 0.02) flow in model was considered as laminar ($Re_p < 1$).

Tab. 1 Calculated input parameters of metal foam

	10 PPI	20 PPI
ϕ [-]	0.966	0.965
D_p [mm]	0.185	0.143
K [m ²]	1.853×10^{-7}	1.10278×10^{-7}
$1/K$ [1/m ²]	5.40×10^6	9.07×10^6
C_1 [1/m]	698.681	905.651

The main part of simulations compared the modified manifold header and conventional manifold header at a selected fluid flow velocities, of which were generated outputs in the form of fluid flow velocities maps. In terms of the velocity profile of the conventional manifold header it can be seen a local turbulences limited to areas of increased flow velocity (See Fig. 3), which distort boundary layers in part near condenser casing. A

clear vortex formed behind area of condenser casing represents area with low value of fluid flow velocity, and thus are with worse heat removal from the condenser (condenser temperature is increased as the heat transfer medium with higher temperature cannot effectively draw heat). A significant negative factor is the subsequent washing of condenser casing with heat transfer medium with higher temperature caused by heat removal from previous condenser casing, therefore it occurs an uneven heat wear. This imperfect heat removal from condenser solves the change of the inner configuration and adding element made of metal foam to the evaluated modified manifold header.

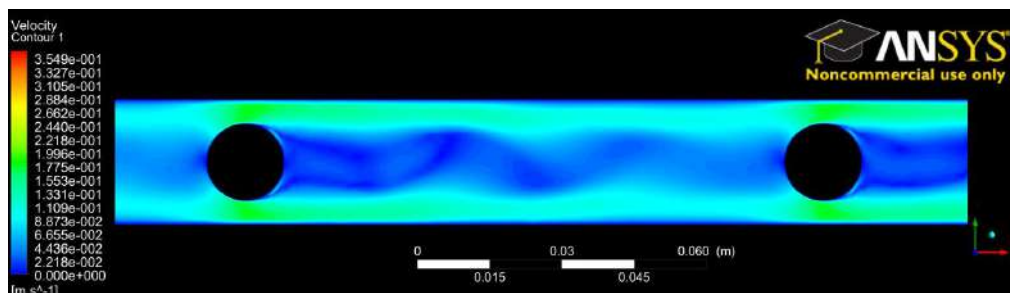


Fig. 3 Close view of fluid velocity map in area between 7th and 8th condenser of conventional manifold header

In contrast to conventional manifold header, on detailed view (see Fig. 4) of fluid flow in heat exchange chamber made of metal foam in modified manifold header it can be seen, that despite small variations in the fluid flow velocity in the different parts of the heat exchange chamber condenser casings are washed almost evenly by heat transfer medium, which flows through the pore structure of the metal foam. Despite the existence of laminar regime of flowing medium, boundary layer does not affect heat exchange process thanks to porous structure, since the heat exchange occurs in its whole volume. During the evaluation of results of conducted CFD analysis was identified potential for modification of heat exchange chamber shape. The nature of modification lies in the flattening of heat exchange chambers and its rotation by angle of 45 degrees due to diagonal directions of flow trajectories. This change will eliminate so-called dead spots in terms of fluid flow rate in some parts of heat exchange chamber, and thus will occur to homogenization of fluid flow in the whole volume of chamber.

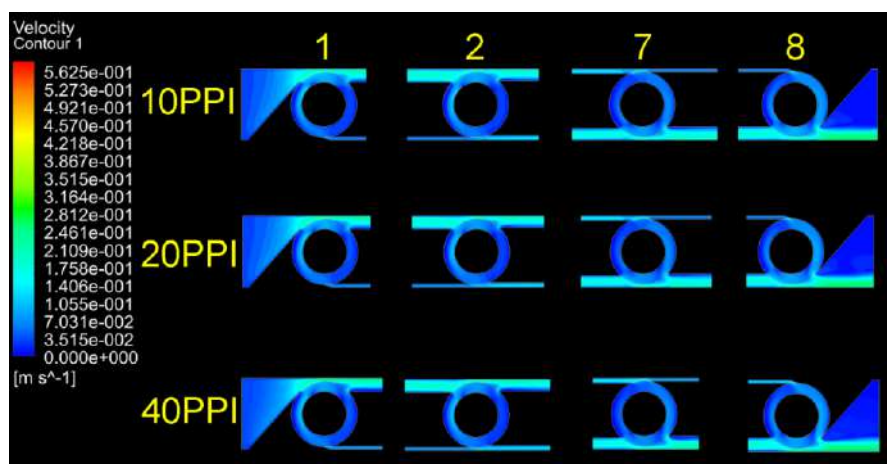


Fig. 4 Comparison of fluid velocity in heat exchange chamber made of metal foam with 10, 20 and 40 PPI

On heat exchange chamber (1st, 2nd, 7th and 8th) depicted in Fig. 4 is visible slight increase in fluid flow velocity for chamber made of 40 PPI metal foam, which is caused by the reduction of flow open area due to the increase in the number of pores (which is consistent with the equation of continuity). However, this at first sight small increase is due to the macroscopic nature of evaluated environment and low values of fluid flow velocities significant.

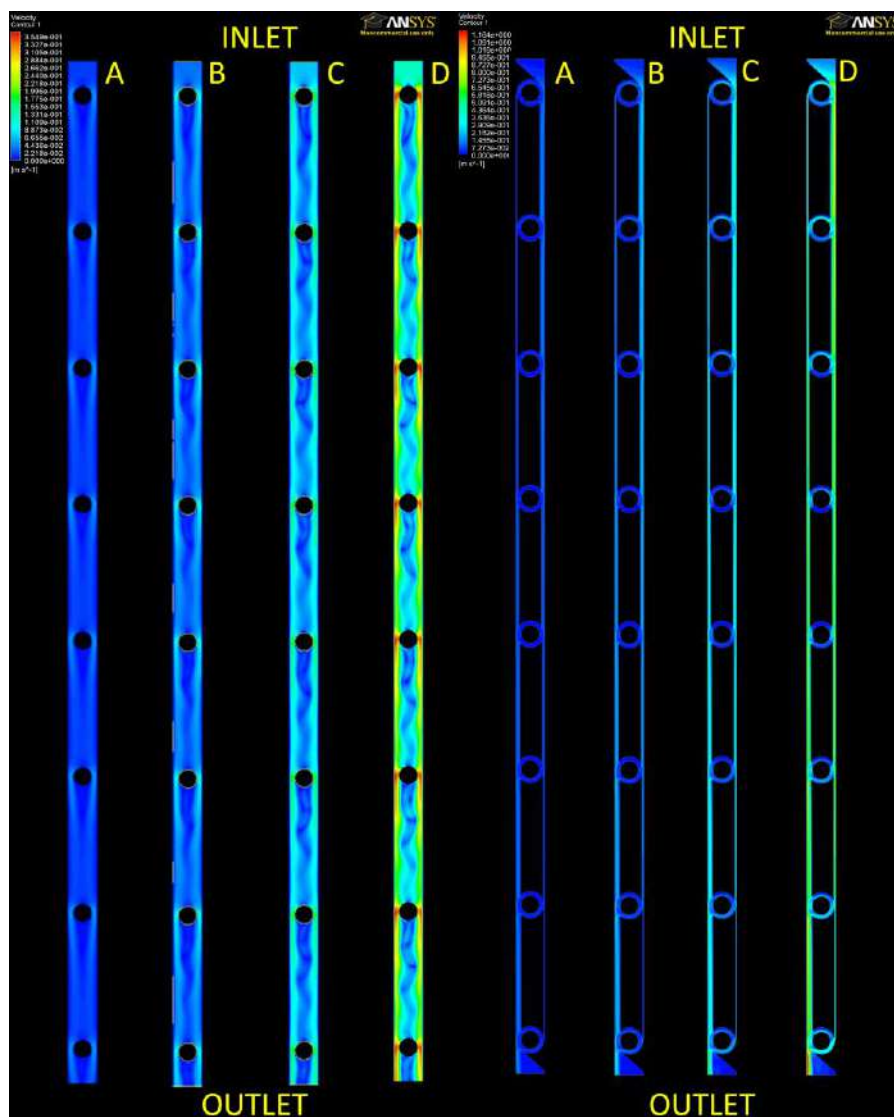


Fig. 5 Fluid flow velocity map for conventional manifold header (left) and modified manifold header (right), where A is volumetric flow rate of 30 kg.h^{-1} , B 60 kg.h^{-1} , C 120 kg.h^{-1} and D 240 kg.h^{-1}

On Fig. 5 is depicted comparison of complete fluid velocity maps of modified manifold header with metal foam element and conventional manifold header, which served as a control standard. Within the comparison are depicted velocity maps for used volumetric flow rates of 30, 60, 120 and 240 kg.h^{-1} . Range of color scale representing values of fluid velocity on Fig. 5 is for both cases different, but contrasting characteristics of flowing heat transfer medium are obvious. Modified inner configuration, which is supplemented not only by heat exchange chamber made of metal foam, but also with hydrophobic pillars improve the conduction of heat transfer medium to each condenser casing, which are tightly enclosed by

metal foam. In this way is increased interface area between heat transfer medium and condenser casing. The advantage of this arrangement is also in reduction of the internal liquid volume of manifold header, what improves the thermal inertia parameters.

4 CONCLUSION

Presented paper dealing with one of the direction of research and development activities of metal foam structures for energy use, which taking place at the Department of Renewable Energy Sources, Faculty BERG since 2008. Range of research and development activities involves research of the metal foam structures at the macro level, implementation of structural elements based on metal foams in devices using renewable energy sources (especially solar energy), designing the heat exchangers and finally linking metal foams and heat accumulators.

The topic of the presented paper was selected stage of research characterized by modification of manifold header for solar vacuum tube collector with constructing element based on metal foam. The main goal of the presented CFD analysis of modified manifold header was comparison of its fluid characteristics with a conventional manifold header. The evaluation of fluid characteristic of the proposed manifold header with CFD analysis showed the adequacy of the approach in conception, which solves identified problems of conventional manifold headers. Changes in heat transfer medium conduction to the condenser casing improves heat removal from them, what also improving the operating conditions of solar collector as well his product life due to the proportional wear of each part. The results of the CFD analysis of the proposed manifold header also suggest possibility of shape change of the heat exchange chamber in a way, which ensures uniform current conduction of heat transfer medium in the whole volume of the heat exchange chamber. Presented outputs in the form of velocity maps thus can serve as a basis for further development and optimization of the final shape and inner configuration of manifold header with structural element based on metal foam.

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